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FLIGHT-MECHANICS PROBLEMS DURING LANDING APPROACH WITH DIRECT LIFT CONTROL, EXEMPLIFIED BY HFB 320 HANSA

D. Hanke and H.-H. Lange

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16. Abstract The problems relating to path control which are encountered during landing approach with jumbo and STOL aircraft are outlined, and special consideration is given to those which occur during steep approaches used for noise abatement. The direct control of lift represents one possibility for alleviating these problems. The capabilities and limits of a DLC system such as was used in an HFB 320 Hansa are evaluated on the basis of simulation and flight test results. The preliminary empirical data from steep two-segment noise-abatement flights with the HFB 320 are reported.

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Notation

$$C_{M\eta} = \frac{\partial M}{\partial \eta} \frac{1}{(\rho/2)V^2 S\, l_\mu}$$

$$C_{We} = \frac{G}{(\rho/2)V^2\, S}$$

$$C_{Z\eta} = \frac{\partial Z}{\partial \eta} \frac{1}{(\rho/2)V^2 S}$$

G	Aircraft gross weight
ILS	Instrument landing system
l_μ	Mean chord length
M	Pitch moment
n_z	Vertical load factor
n/α	Load factor over angle of attack
q	Rate of pitch
$\dot{q}(0)$	Pitch acceleration at time $t = 0$
S	Wing area
V	Velocity
Z	Vertical force
α	Angle of attack
γ	Path angle
η	Elevator angle
η_F	Flap angle
$\hat{n}_{nsp}$	Dimensionless damping exponent
ω_{nsp}	Undamped frequency of rapid angle-of-attack oscillation
$\hat{\omega}_{nsp}$	Dimensionless undamped frequency of rapid angle-of-attack oscillation
ρ	Density
σ_i	Standard deviation of variables i
θ	Angle of pitch

FLIGHT-MECHANICS PROBLEMS DURING LANDING APPROACH WITH DIRECT LIFT CONTROL, EXEMPLIFIED BY HFB 320 HANSA

D. Hanke and H.-H. Lange

1. Introduction /5*

Relatively severe requirements for the maintenance of a flight path are associated with the introduction of steep approach paths such as those necessitated for reasons of noise, for example [1, 2]. Control problems occur in the maintenance of a prescribed glide path, in flattening-out and in touch-down, particularly when jumbo aircraft and slow-approaching STOL aircraft are used. Even several years ago, studies were made on the use of additional control parameters so that the specified requirements could be satisfied without increasing the pilot's workload and impairing safety [3-7]. An additional control parameter which is available was wing lift, which makes direct vertical control of the aircraft relative to the flight path possible. This type of control has become known under the name "direct lift control" or DLC. Thus DLC refers to a control aid which can produce positive or negative lift almost instantly in the vicinity of the center of gravity without generating great changes in moment. The positive or negative lift can be produced here by the use of nose or trailing-edge flaps on the wings, spoilers, or by the discharge of powerplant bleed air.

2. Approach Problems

What problems during approach and particularly during steep approach make the introduction of a new type of control appear necessary?

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* Numbers in the margin indicate pagination in the foreign text.

In conventional aircraft, flight path control is primarily accomplished by means of the elevator, i.e., a change in lift is produced via a change in angle of attack and thus via a change in the aircraft's angle of pitch. The path-change response or vertical-acceleration response to an elevator command is thus determined by the rapid angle-of-attack oscillation of the aircraft.

The frequency of rapid angle-of-attack oscillation ω_{nsp} /6 decreases with incresing aircraft dimensions and with the associated greater pitch moment of inertia, however, which results in sluggish pitch behavior on the part of the aircraft. Whereas the period of rapid angle-of-attack oscillation is only 3 or 4 sec in the landing approach range for the HFB 320, it rises to 6 or 8 sec in the case of the DC 8 and 8 to 12 sec in the case of the Boeing 747. The time curves shown in Fig. 1, which clearly show the sluggish accleration response associated with large aircraft, are obtained for the vertical acceleration response of the three aircraft to an elevator command.

A negative effect on rapid path change results from the fact that the force generated by the elevator for rotating the aircraft works against the desired path change, since the entire lift of the aircraft is initially reduced upon a climb command until the aircraft has rotated and additional lift can build up. This effect results in an initial reversal of aircraft response, which is particularly manifest in aircraft with short control surface lever arms.

Correspondingly sluggish behavior can be expected on the part of future STOL aircraft, since the frequency of rapid angle-of-attack oscillation decreases as approach velocities decrease [8], as Fig. 2 shows in the root plane. In particular, STOL aircraft with powered lift exhibit large weight coefficients C_{We}, due to their low approach velocities, and the rapid angle-of-attack oscillation can degenerate to an aperiodic motion.

Sluggish aircraft responses are particularly critical during steep approaches, since precision control of sinking speed is required for flattening-out and for the transition from a steep to a flat approach segment. Fig. 3 shows that the limit for sinking speed which is still acceptable for conventional aircraft, according to [1], is about 1000 ft/min. Steep approaches, for example at 6°, require sinking speeds which are twice as high as before for a given approach speed, however; these are already far outside the tolerable range. In addition, the level of thrust for steep approach is very low, causing powerplant run-up times which are considered unacceptable by the pilots. One possibility for making steep approaches flyable is to reduce approach velocity, although this would be feasible only within limits, and another is /7 to increase maneuverability for rapid and accurate path changes. Direct lift control offers one possibility for improving path control. Fig. 4 shows the difference in aircraft vertical response with and without DLC to an abrupt-change command and the course which a path correction takes. The rapid accelerative reaction due to a direct change in lift at the wing is essentially independent of the aircraft's size. In addition, the aircraft with DLC can be controlled parallel to the path with an almost constant pitch attitude.

A criterion for evaluating the maneuverability of aircraft which is also applied to the task of maintaining a path during landing approach is the control anticipation factor (CAP), which is defined as follows:

$$\mathrm{CAP} = \frac{\dot{q}_{(0)}}{n/\alpha} = \frac{\omega_{nsp}^{\;2}}{n/\alpha} \quad .$$

The CAP factor represents the ratio of pitch acceleration at time t = 0 to the load factor n/α which is reached. The values required as per MIL-F-8785 B [9] can be taken from Fig. 5. The CAP values plotted for several aircraft show the impairment of maneuverability of STOL aircraft and jumbo aircraft. Regarding the limits which are plotted, however, it is stated in the background information on MIL-F-8785 B [10] that they do not represent absolute limits. Rather, the problems which occur at low ω_{nsp} values should be overcome with new types of control. Direct lift control represents such a possibility. To be sure, too few data are so far available to allow exact statements to be made here, particularly as to how a DLC system must be structured in order to impart acceptable flight characteristics to aircraft with low CAP factors for the task of maintaining a flight path.

3. Studies on Direct Lift Control /8

The studies on the application of DLC which are in progress in the Aircraft Flight Mechanics Department of the Institute for Flight Mechanics have the goal of delimiting the ranges within which the use of a DLC system appears to be reasonable and necessary, be it for manual control or as part of an integrated path control system. Moreover, criteria for flyability must be found for the application of such a system.

The experiments which have so far been conducted, which are reported here, cover the following subtasks:

1. Simulation studies on possibilities for improving path control accuracy by means of a simple DLC concept, exemplified by the HFB 320 Hansa.

2. Flight-testing a DLC system which has proven itself in simulation, and evaluation of flyability.

3. Employment of DLC in steep, two-segment noise-abatement approaches.

3.1. Studies with Stationary Flight Simulator

A DFVLR HFB 320 which was equipped with a lift control system as part of the "Aircraft with Variable Flight Characteristics" project, likewise conducted by the Aircraft Flight Mechanics Department, was available for flight tests with a DLC system. The landing flaps, whose rate of travel was increased from 2.5°/sec to 10°/sec, were to be used for lift control. A detailed description of this system is given in Section 3.2.1.

The simulation studies which ran parallel to development of the electrical landing flap positioning system were therefore based entirely upon the characteristics of the Hansa, with special consideration given to the performance and characteristics of the flap system and the technical feasibility of producing a DLC system.

Since the design and performance of a DLC system are primarily a function of aircraft configuration and the lift control system employed, the following consequences for the HFB 320 Hansa resulted from the use of landing flaps for lift control: /9

In order to be able to generate positive and negative vertical forces in the reference flight state, the flaps had to be actuated about an extended position; 20° was selected as the central flap position. In order to guarantee a sufficient difference from stalling speed, approach velocity was set at 150 kn, corresponding to 1.3 V_S at a flap angle of 0°. The change in lift coefficient which can be achieved with flap changes was $\Delta C_L \sim 0.6$. In the reference flight state selected, this value corresponds to a change in load factor of $\Delta n_z = +0.5$ g and $\Delta n_z = -0.34$ g. Studies [5] have shown that load factor changes no greater than $\Delta n_z = \pm 0.15$ g are required for path control.

In Fig. 6, lift coefficient C_L is plotted for the HFB 320 for various flap angles as a function of angle of attack α for a 6° approach. The figure also shows the principal difference between DLC and elevator control: While a change in C_L is achieved only through a change in α and thus through a change in the aircraft's pitch attitude in the case of elevator control, lift is varied in the case of DLC by actuating the flaps at constant angle of attack.

Fig. 7 shows required thrust as a function of velocity for a 6° approach. For this state of flight, the spoilers must be extended to increase drag in order to keep thrust above the idle level and to still have a range of thrust available for speed corrections. The reference state of flight for the 6° approach with DLC and the boundaries on the flyable range, which is delimited by stalling speed and the speed which is permissible with landing gear extended, have been drawn in.

The extent to which manual path control can be improved in the Hansa by means of a simple DLC system and the extent to which the changes in drag generated upon flap actuation tax the pilot in his /10 activities were first found in simulation studies. A stationary flight simulator was used for these studies. The longitudinal motion of the Hansa was programmed in nonlinear form, including landing flap positioning system dynamics, on an EAI 640 hybrid system. In addition, the roll degree of freedom was taken into consideration in order to give the approach a more realistic form for the pilot. The simulated cockpit had a control stick for controlling the pitch and roll axes and a push lever to control speed. Control forces were generated by spring elements. Information available to the pilot included altitude, aircraft speed, sinking speed, pitch and roll attitudes, and deviation from aircraft speed and from glide path. In addition, frontal, vertical and roll gusts could be applied. The pilot's task was to keep deviation from glide path as small as possible and maintain aircraft speed within ±5 kn.

The lift control system consisted of a connection between elevator and landing flap such that the landing flaps extended when an elevator command was given and generated additional lift. The superposition factor between elevator and flap was chosen so that pitch attitude remained almost constant during flap operation time. Although the changes in drag due to flap actuation affect speed, the maintenance of speed, glide path and pitch attitude could be improved with this system.

Fig. 8 shows the results with DLC as compared to the basic aircraft (A). The times are shown for deviation from a given tolerance range as referred to total flight time. Deviations could be reduced with the DLC system for speed, glide path and pitch attitude (B). The results could be further improved by using a propulsion regulator (C). Moreover, the figure shows -- as was also to be expected -- an increase in throttle activity when the flaps are used for lift control. To be sure, maintaining speed with DLC was not found to be particularly difficult by the pilot. Studies with a washout element, as proposed by Pinsker [4] and used in studies with a DC-8 [5], worsened the pilot's evaluation, since the flaps, in returning after an elevator command, produced a change in pitch attitude which the pilot had not commanded and which he perceived to be disturbing.

Tests in which the landing flaps could be actuated by means of an added thumb wheel in the control stick showed that this type of control was considered unflyable by the simulation pilot, since the pronounced coupling between pitch attitude, vertical motion and forward speed resulted in considerable problems in coordinating rudder and flap actuation. The use of a pitch attitude control accompanying DLC with thumb wheels produced /11 very good results, on the other hand, since the pilot could concentrate entirely on maintaining his glide path. Previous studies [7] showed, though, that a separate control lever for lift control puts an additional load on the pilot. On the basis of technical possibilities and the limited time available for flight testing with the Hansa, the decision was made to flight test only DLC concepts B and C. The flight tests with a propulsion regulator could no longer be conducted, however, due to time limitations.

3.2. Flight Tests

3.2.1. Description of Tests

A DFVLR HFB 320 Hansa (Fig. 9) was used as the test unit for testing direct lift control. The aircraft had been equipped with an electrical landing flap and thrust control system at Messerschmitt-Bölkow-Blohm, Hamburg Aircraft Construction Division, as part of the "Aircraft with Variable Flight Characteristics" project. Both systems were developed by MBB in collaboration with the DFVLR.

Fig. 10 provides an overview of the electrical landing flap positioning system: The electrical flap input signal goes to the regulator, operating with position feedback, which activates one torque motor each for the right and left flaps. The torque motors act on the shafts of the basic landing flap positioning system directly via a gearbox; the shafts in turn actuate the flap hydraulic cylinders, which where modified for the higher actuation speed of 10°/sec.

Fig. 11 shows the principle of the lift control system used in the HFB 320. Elevator position is picked up electrically and fed, via an analog computer, to the landing flap /12 positioning system, which adjusts the flaps in direction and amplitude as desired. Fig. 11 also shows the moments and forces on the aircraft which occur when a control stick command in the nose-up direction is given. The most favorable ratio of resultant lift and moment in terms of flyability was to be determined with flight tests.

Fig. 12 provides an overview of the aircraft and the systems used for the flight tests. The landing flap positioning system is again shown, with the two torque motors and the control electronics, as well as the thrust control unit in the hydraulics area and the plug-in control unit. The electrical positioning system is operated and monitored by means of an operating mode instrument located in the cabin. The operating mode instrument was developed and built by the Measurement Engineering Department of the Institute for Flight Systems Dynamics of the DFVLR in Oberpfaffenhofen. The systems can each be cut in and out without jarring via luminous buttons on an operating panel in the cockpit (central console) and an operating panel in the cabin, through established switching sequences. The system is designed so that improper operation produces no effects and that the system is automatically switched off or further switching is blocked if system errors occur. On the left, next to the operating console, are analog computing elements, on which elevator-flap superposition was executed and which were to be used as propulsion regulators. A flexible airborne measurement system which was developed and built by the Flight Measurement Engineering Department of the Institute for Flight Mechanics provided for the acquisition of about 20 measured quantities recorded on the aircraft on a 50-channel photographic recorder: 10 variables were recorded on an analog magnetic tape unit and simultaneously telemetered to the ground station for quick-look and recorded.

3.2.2. ILS Approaches with Direct Lift Control

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For the evaluation of DLC, long 2.5° ILS approaches were made from 3800 ft above ground, the pilot having the task of maintaining the prespecified speed of 150 kn and the glide path as exactly as possible. The landing flap positioning system was cut in by the copilot at a certain distance prior to reaching the glide path, and the landing flaps were extended to 20° by means of a positioning potentiometer on the starboard controls. After the glide path had been reached, the aircraft was stabilized, the elevator was kept fixed, and the elevator signal was adjusted to a flap angle of 20° by the test engineer. After adjustment had been accomplished, the elevator flap connection was superimposed by the test engineer with the preselected transfer ratio. This put the aircraft into the DLC mode. After landing approach, the DLC system was cut out by the pilot at an altitude of 500 ft and the go-around maneuver was initiated.

3.2.3. Steep Approaches

In order to obtain information concerning the problems associated with steep, noise-abatement approach paths and to test possibilities for path control with DLC, a total of 12 steep approaches were flown with dogleg paths. The course followed in the test is outlined in Fig. 13. The approach profile consisted of a steep 6° segment followed by a 2.5° segment; the intersection on the 2.5° ILS glide path was initially set at 800 ft GND for safety reasons. The path angle was calculated on board the aircraft from the angle of pitch and the angle of attack and was displayed to the pilot on a longitudinal-scale instrument. The 6° descent was made at a distance of 8.44 n.m. from the touch-down point, which was determined by a VOR NDB cross bearing fix. The transition to the 2.5° ILS glide path was made with a conventional glide path indicator. In the steep approach test, a videocamera was also employed with which all pilot activities were recorded. The process used in cutting DLC in and out was executed as in the 2.5° approaches with DLC. The DLC system was cut in shortly after transition to the 6° path and cut out after the flattening-out arc. The overall flight path was also measured with a ground radar system. Aircraft noise was simultaneously recorded at eight noise measurement points installed along the projected approach path. Radar measurement was executed by the Institute for Aircraft Control, the noise measurements by the Institute for Propulsion Systems of the DFVLR. /14

4. Flight Test Results

4.1. Behavior of the HFB 320 Hansa with DLC

In order to determine the behavior of the HFB 320 Hansa with DLC, elevator abrupt-change inputs were used with elevator-flap ratios of K = 0, 5, 10, 15, 20, and 30, and aircraft responses were recorded.

The Hansa's response to an elevator abrupt-change command in the nose-up direction with and without DLC (K = 10) is shown in Fig. 14.

The following differences can be recognized in DLC as compared to elevator control:

1. The rise in vertical acceleration is considerably steeper, maximum increase in acceleration amounting to ∿0.14 g.

2. Path change takes place more rapidly.

3. The change in pitch is approximately zero during flap operation time, so pitch angle remains smaller by a total of 2°.

4. The change in angle of attack becomes negative, due to the lift motion which is assumed.

5. The time elapsing until the aircraft reacts is not reduced with DLC, due to the dead time in the flap positioning system (∿0.25 sec) and the relatively low flap positioning speed of 10°/sec. The aircraft first reacts to the elevator until the flap becomes operant; this can be seen particularly in the curve of vertical acceleration.

Higher superposition factors than 15 produce little change /15 in the aircraft's short-term response, since the flaps run against their stops in this case. At very small elevator amplitudes and high superposition factors ($K \geq 20$), an initial reversal in pitch response could be detected.

4.2. ILS Approaches With and Without DLC

In order to obtain an overview of the performance of DLC as compared to elevator control, the test data were evaluated statistically. Evaluation was based on 15 ILS approaches made by two DFVLR pilots, with the number of approaches divided approximately equally between the two.

Fig. 15 shows the statistical evaluation of the ILS approaches with and without DLC. Standard deviations are plotted for elevator and landing flaps, as well as for rate of pitch, as are the vertical load factor, angle of attack, pitch attitude, path angle and glide path deviation. Standard deviation can be interpreted as a measure of the precision with which a value is maintained and, in the case of positioning quantities, as a measure of pilot activity. The results with DLC exhibit an unequivocal trend. The best results are obtained for an elevator-flap transfer ratio of $K = 10$, corresponding to $C_{M\eta}/C_{Z\eta} = -0.034$, in contrast to elevator control, for which $C_{M\eta}/C_{Z\eta} = 1.56$.

Smaller standard deviations for elevator, rate of pitch, angle of attack, pitch attitude, path angle and glide path deviation are obtained for DLC with K = 10 than for the basic aircraft. These results show that the glide path can be maintained more accurately with DLC with a simultaneous reduction in pitch attitude change and elevator activity. A more exact statement regarding pilot elevator activity can only be made, however, when the corresponding performance spectrum becomes available.

At K = 15, the results are no better than for the basic aircraft, and at K = 20, the higher elevator deviation indicates increased pilot activity, standard deviation becoming higher for flight path deviation than in the case of the basic aircraft. The trends indicated here are also confirmed by the pilot's evaluation. Fig. 15 shows, moreover, that load factor changes increase with increasing flap superposition. It is also conspicuous that the flap angles used for control exhibit a standard deviation with a very small range of only 3° in the case of DLC. /16

A count of thrust adjustments per approach showed that the number of throttle activities per approach remained approximately constant with and without DLC. Throttling amplitudes increased with increasing elevator-flap superposition, however; the pilots were unaccustomed to this and were subjected to an additional load. If large control inputs ($\eta_F \geq 10°$) were used to correct for glide path deviations, considerable changes in thrust were necessary in order to maintain speed at the prescribed value.

4.3. Steep Approach Results

Conclusive statements as to whether steep approaches can be made more easily with DLC than with normal elevator control on the HFB 320 cannot yet be made on the basis of the few steep approaches that were possible, which primarily served to establish approach procedure. A number of results are obtained, however, which are valuable for future work:

On a 6° approach at 150 kn approach speed, sinking speed was 1600 ft/min. Steep approach caused hardly any problems for the pilots, with or without DLC, under the above-mentioned restrictions; in particular, the high sinking speed was not found to present a burden. The important problems did not occur so much in the flattening-out phase as in the stabilization phase following the transition to the 2.5° segment. Since velocity had to be reduced to 125 kn in this region by extending the flaps to 50°, a considerable burden was placed on the pilot. In the opinion of the pilots, the primary difficulty was that the exact time and the magnitude of the necessary thrust adjustment were not known exactly. After a little training, they felt that the stabilization phase did not represent a serious problem. /17

Fig. 16 shows a radar plot of a two-segment approach compared to a stand approach. It can clearly be seen that the 6° descent is very smooth, and deviations from the glide path are within the usual tolerances even after the 2.5° transition. The transition from 6° to 2.5° occurred a little too late in this approach, but could be executed exactly, without overshoot, as the radar plot shows. The 6° approach and the flattening-out arc were flown with DLC. The somewhat flatter approach path than the desired 6° path resulted because of the tail wind which was blowing during the approach. The wind correction in the γ-readout had not been adjusted accurately.

Fig. 17 shows the difference in control during the flattening-out arc from the 6° path to the 2.5° path. It can be seen clearly that the pilot quite unequivocally attempted to achieve a constant pitch attitude in the case of elevator control. The elevator curve is typical of a rapid path change which the pilot produces by over-controlling when he initially makes the elevator angle greater than necessary and then retracts it. The elevator curve for DLC control is quite different: The elevator angles are very small, and it can clearly be seen that direct control of the path is possible, the changes in pitch attitude remaining very small.

4.4. Pilot Evaluation

The pilots expressed themselves to the effect that the aircraft could be controlled very accurately, with small glide path deviations, as a result of the DLC control installed in the Hansa, and that the small changes in pitch attitude were found to be pleasant.

If relatively large displacement occurred, however, flap /18
changes of more than 10° resulted in velocity corrections, and the pilots had serious problems restabilizing the aircraft. The problems associated with large displacement led to a desire to have a propulsion control installed in order to reduce the burden on the pilots.

With a transfer ratio of K = 20 between elevator and flap, aircraft control became too sensitive, and the flaps continually extended and retracted by large amounts. The associated changes in speed required continual thrust corrections. The burden on the pilots was found to be unreasonably high. The changes in control force during flap operation time were also found to be slightly disturbing.

5. Summary

The flight tests program which was executed yielded the following results:

1. The use of direct lift control with a link between elevator and flaps permits more rapid path changes during landing approach with simultaneously smaller changes in pitch attitude.

2. For small glide path deviations, path corrections could be executed very precisely, and the behavior of the aircraft was found to be pleasant. Only when relatively large displacements from the glide path occurred did the necessary large control deflections result in increased throttling activity, due to the drag behavior of the flaps, so the use of a propulsion regulator appears necessary.

3. During steep approaches, maintenance of flight path along the 6° segment presented no serious problem in the HFB 320 Hansa with or without DLC in terms of flyability.

4. Flattening-out characteristics can be improved with direct lift control.

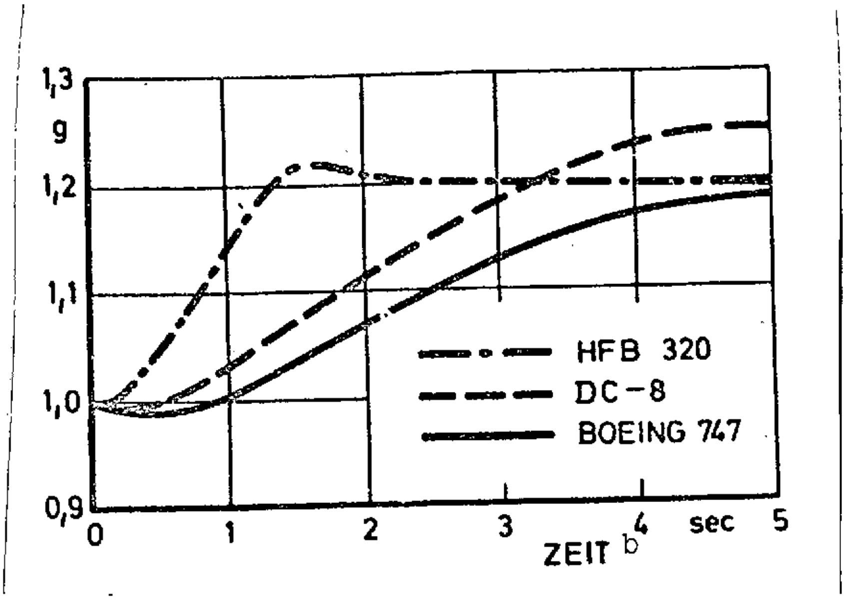


Fig. 1. Comparison of vertical acceleration response for aircraft of various size.

[Note: Commas in numerals are equivalent to decimal points.]

Key: a. Vertical acceleration
b. Time

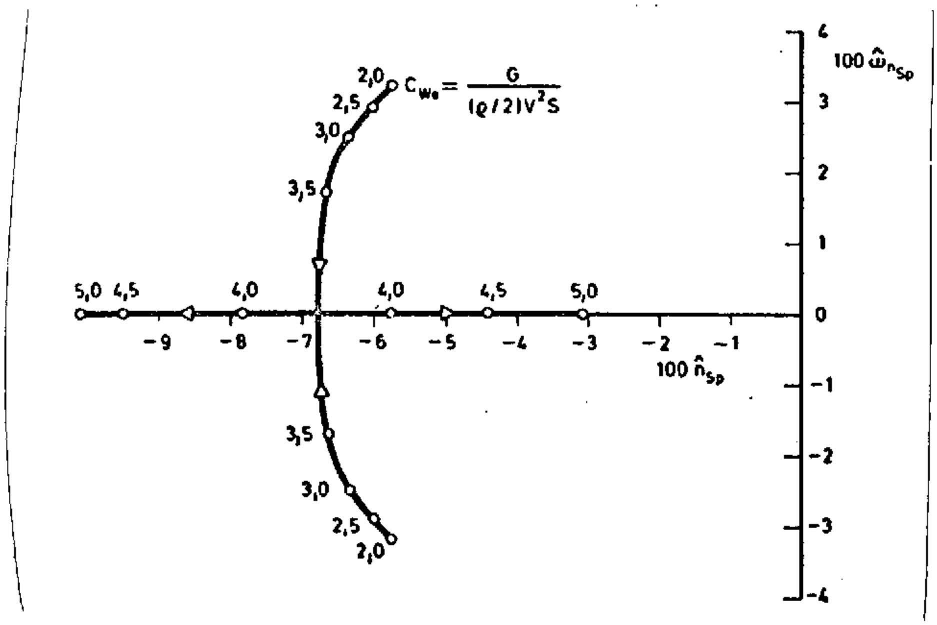


Fig. 2. Root loci for rapid angle-of-attack oscillation as a function of approach speed, from [6].

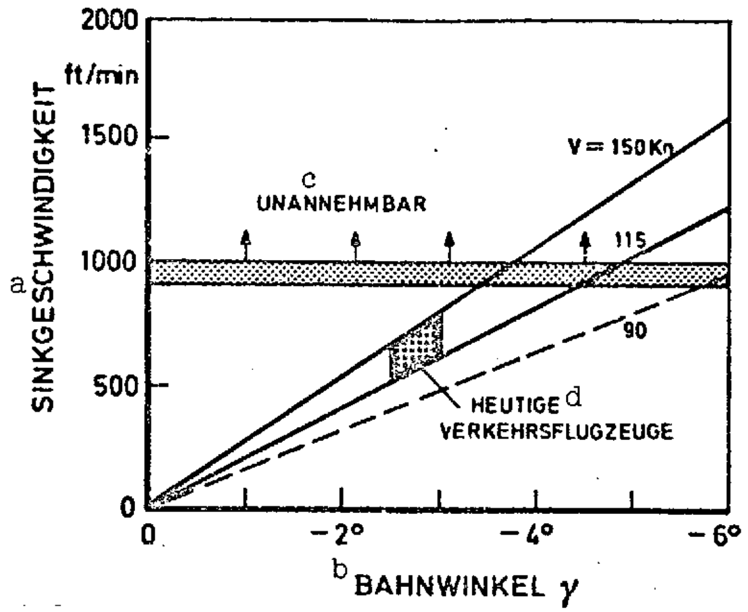


Fig. 3. Sinking speed as a function of path angle, from [7].

Key: a. Sinking speed
b. Path angle
c. Unacceptable
d. Contemporary air liners

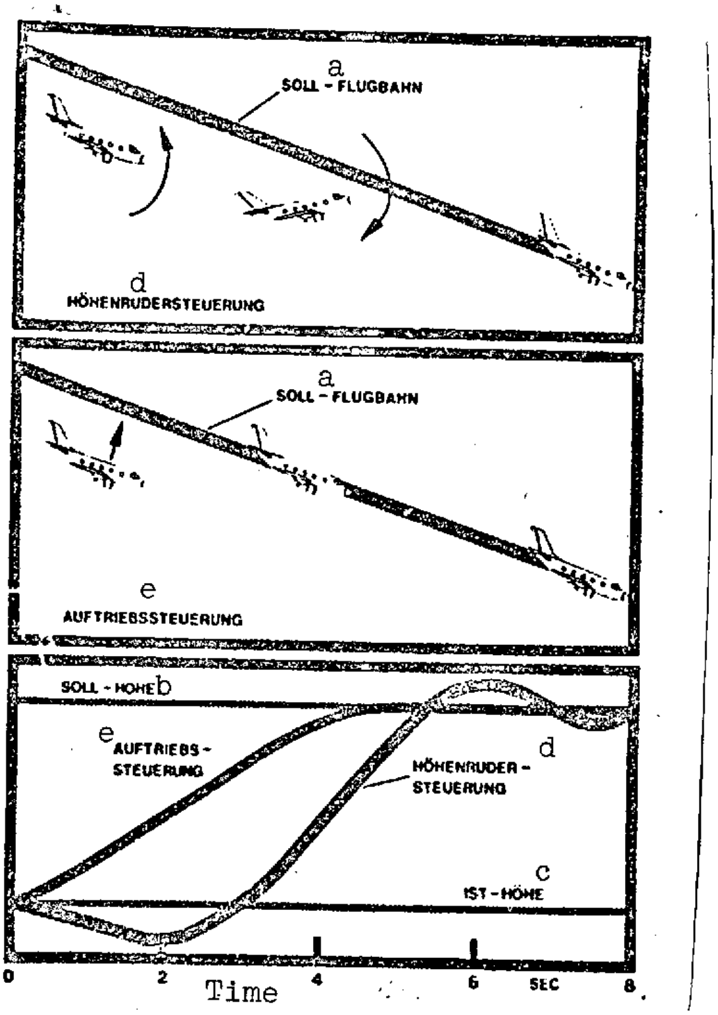


Fig. 4. Direct lift control.

Key: a. Desired flight path
b. Desired altitude
c. Actual altitude
d. Elevator control
e. Lift control

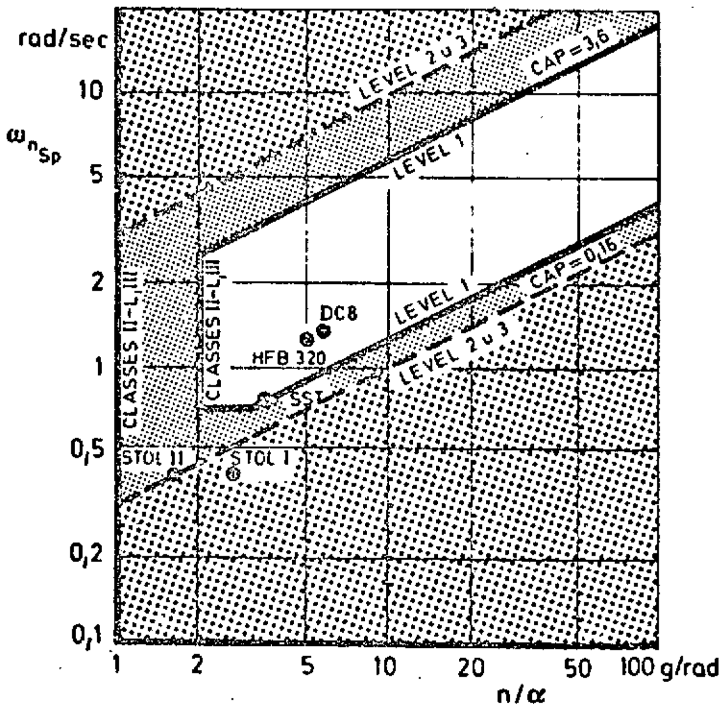


Fig. 5. Maneuverability requirements for landing approach as per MIL-F-8785 B.

Key: u = and

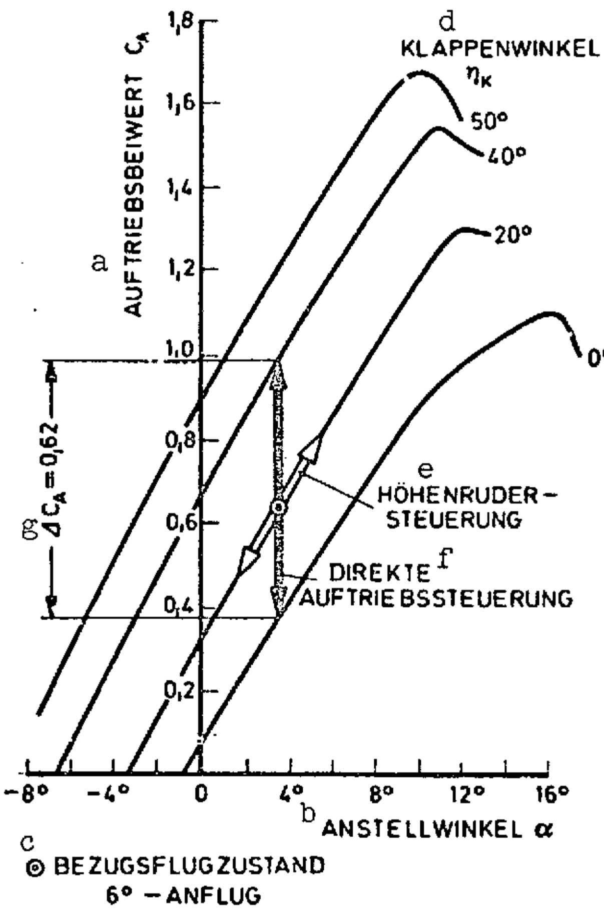


Fig. 6. Possibilities for varying lift in the HFB 320.

Key: a. Lift coefficient C_L
b. Angle of attack
c. Reference flight state, 6° approach
d. Flap angle η_F
e. Elevator control
f. DLC
g. ΔC_L

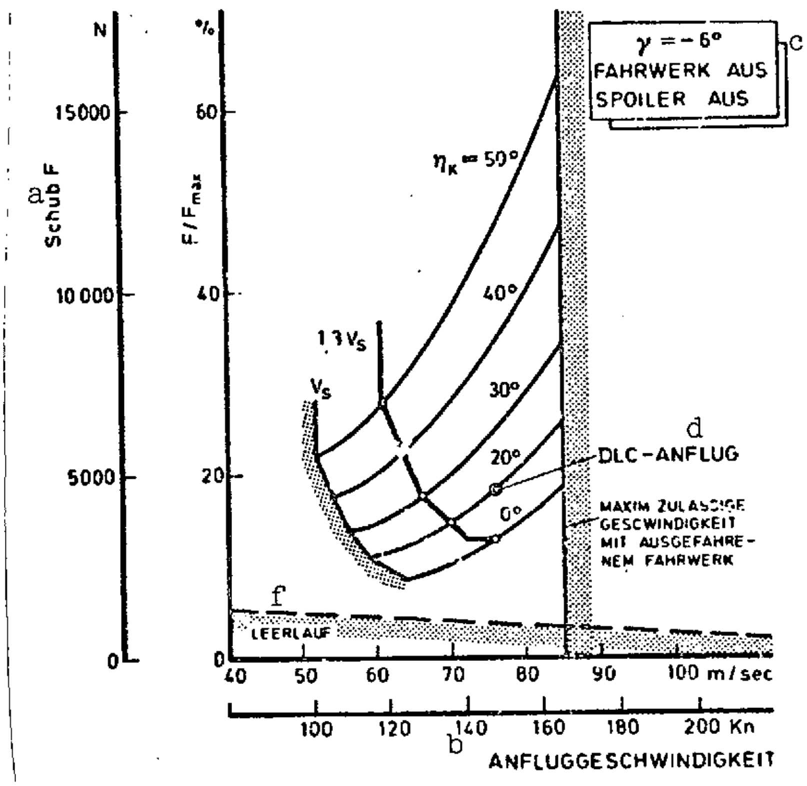


Fig. 7. 6° approach range for the HFB 320.

Key:
- a. Thrust
- b. Approach speed
- c. Landing gear extended, spoilers extended
- d. DLC approach
- e. Maximum permissible speed with landing gear extended
- f. Idle

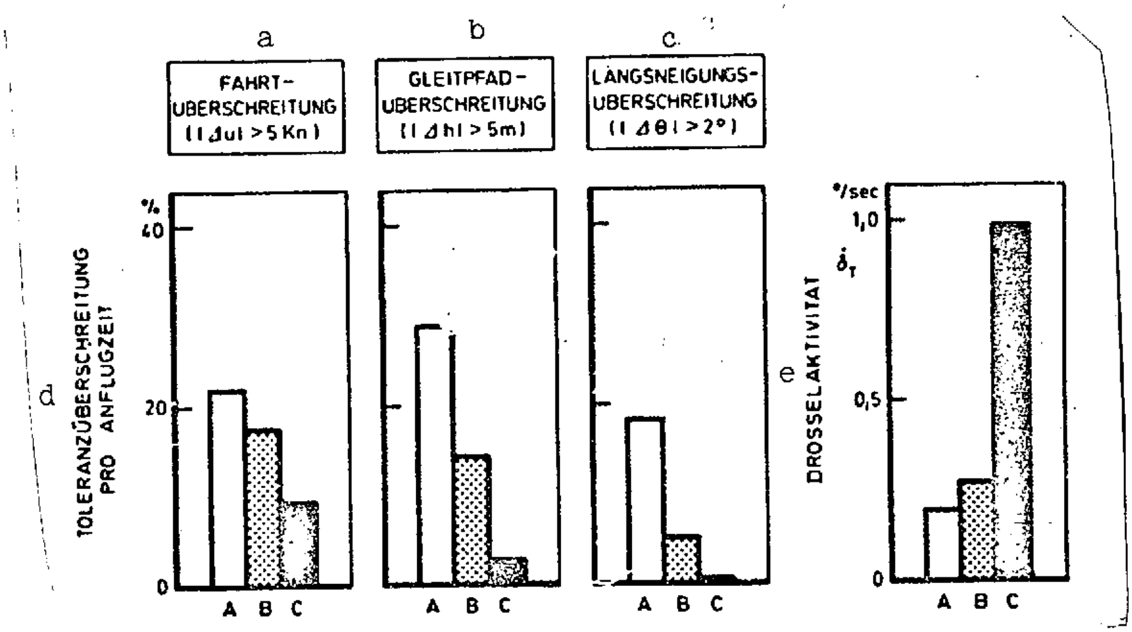


Fig. 8. Comparison of landing approaches with gust effects, with and without DLC (simulation).

Key: a. Speed deviation
b. Glide path deviation
c. Pitch angle deviation
d. Deviation beyond tolerance expressed as percentage of approach time
e. Throttle activity
A. Basic aircraft
B. DLC
C. DLC + propulsion regulator

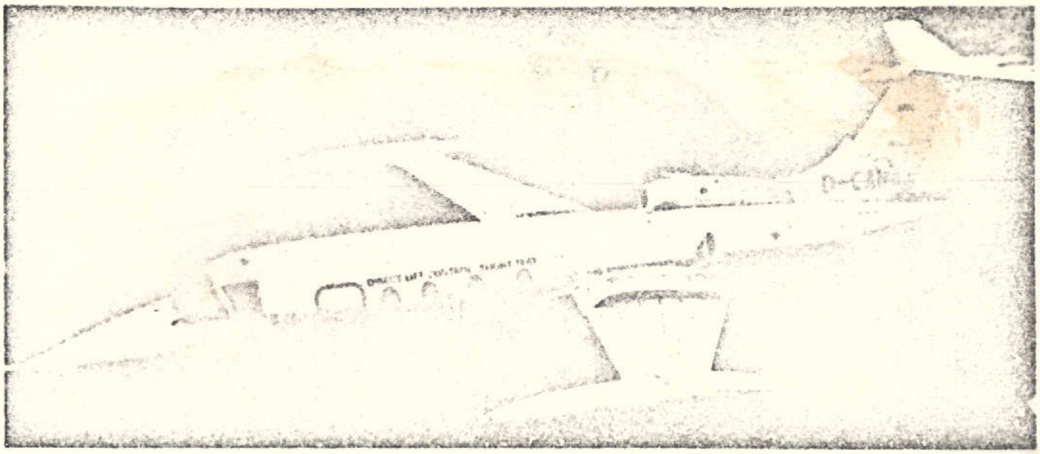


Fig. 9. DLC test unit, HFB 320 Hansa.

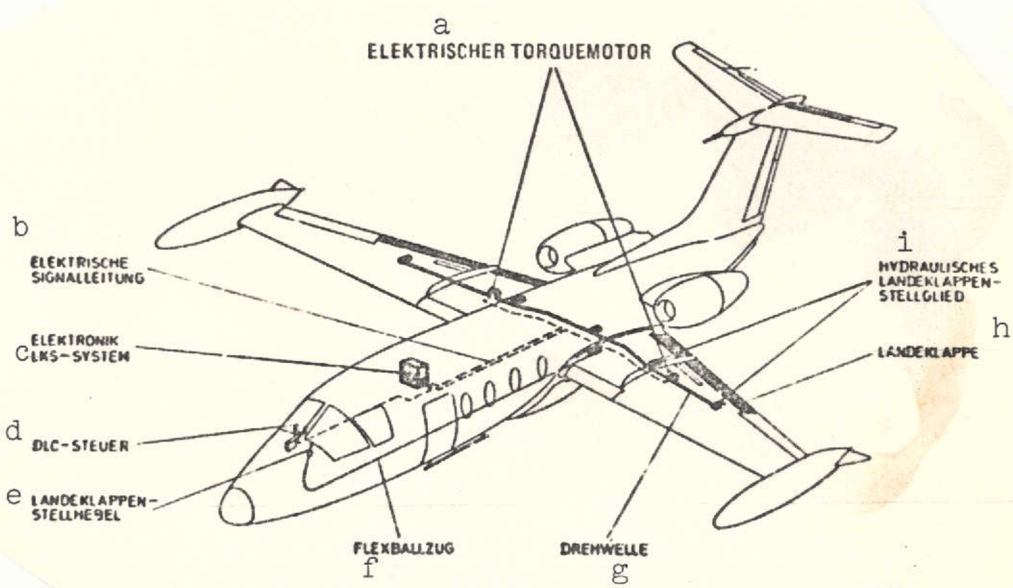


Fig. 10. Landing flap positioning system: installation overview.

Key: a. Electric torque motor
b. Electrical signal line
c. Electronics, landing flap positioning system
d. DLC control lever
e. Landing flap positioning lever
f. Flexball line
g. Shaft
h. Landing flap
i. Hydraulic landing flap control element

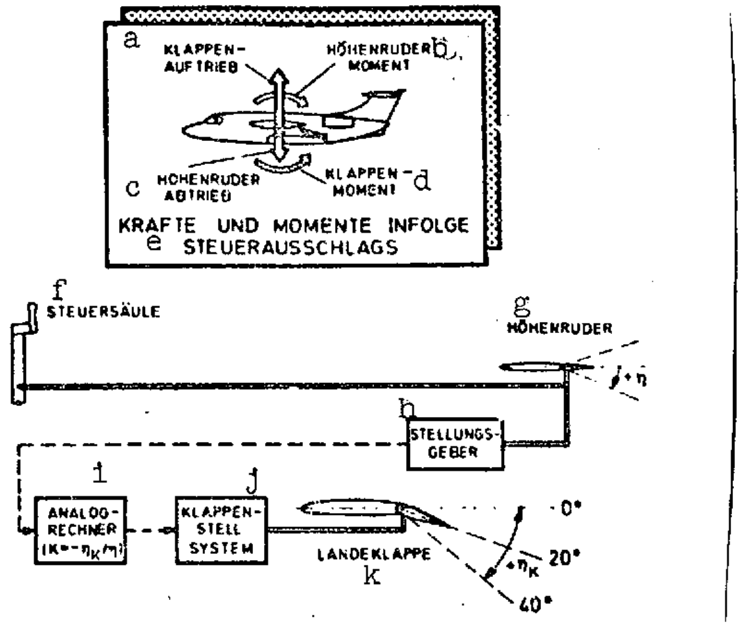


Fig. 11. Schematic of lift control in the HFB 320.

Key:
- a. Flap lift
- b. Elevator moment
- c. Elevator negative lift
- d. Flap moment
- e. Forces and moments due to control-surface movement
- f. Control column
- g. Elevator
- h. Remote position indicator
- i. Analog computer
- j. Flap positioning system
- k. Landing flap

η_K = flap angle

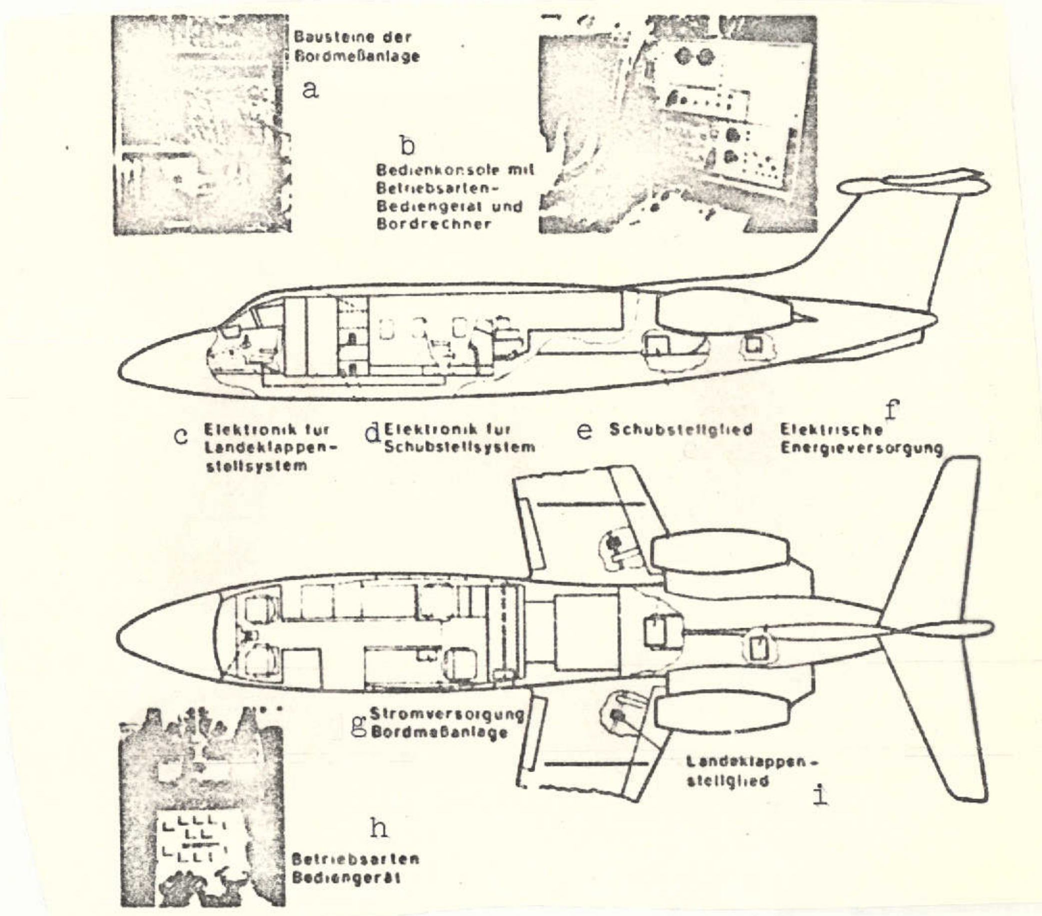


Fig. 12. HFB 320 -- Overview of system.

Key:
a. Modules in airborne measurement system
b. Control console with operating mode control unit and airborne computer
c. Electronics for landing flap positioning system
d. Electronics for thrust control system
e. Thrust control element
f. Electrical power supply
g. Power supply for airborne measurement system
h. Operating mode control unit
i. Landing flap control element

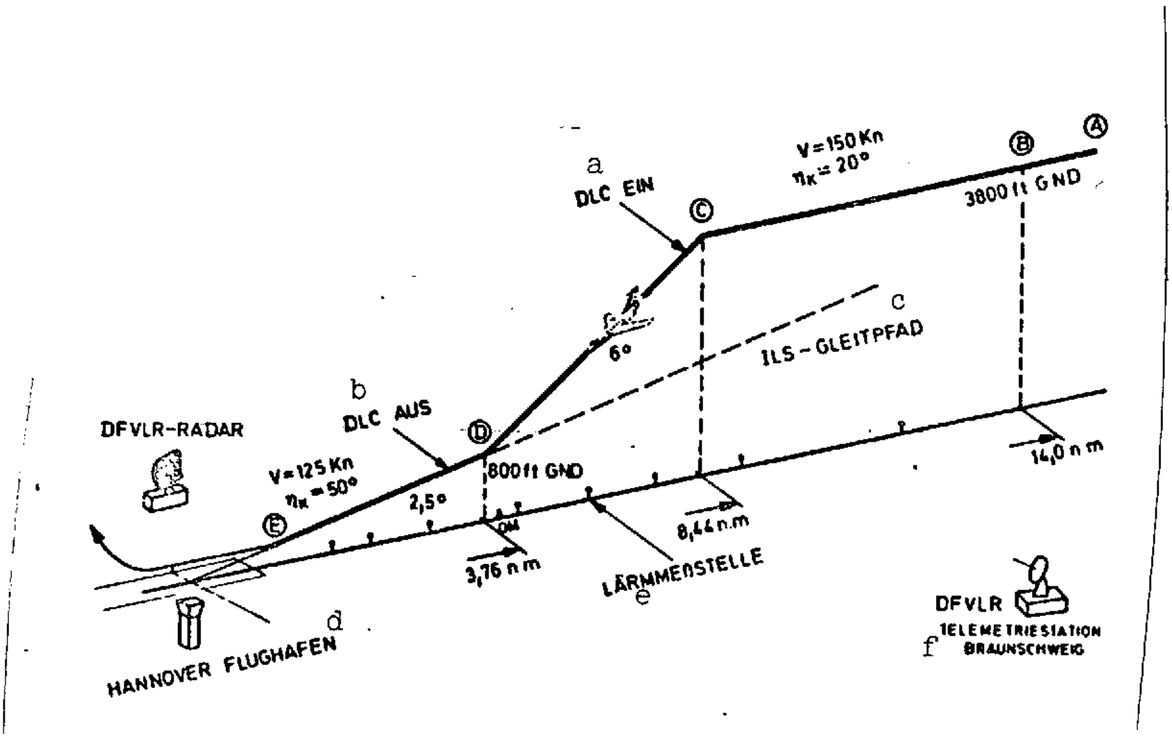


Fig. 13. Two-segment noise-abatement approach path (overview for test).

Key: A. On localizer
B. Measurement systems on
C. 6° transition
D. 2.5° transition
E. Beginning of go-around
a. DLC on
b. DLC off
c. ILS glide path
d. Hannover airport
e. Noise measurement point
f. Braunschweig telemetry station
η_K = Flap angle

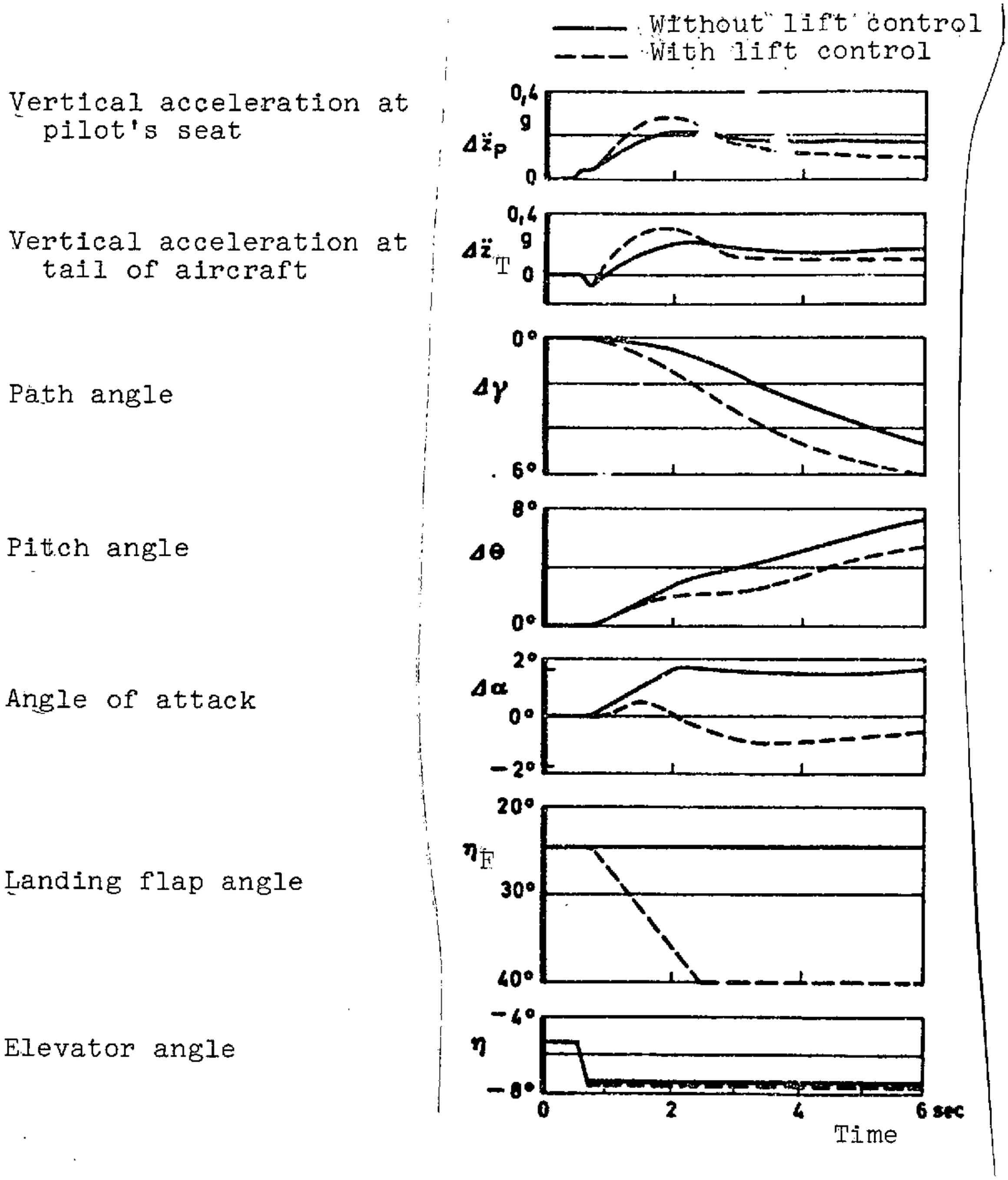
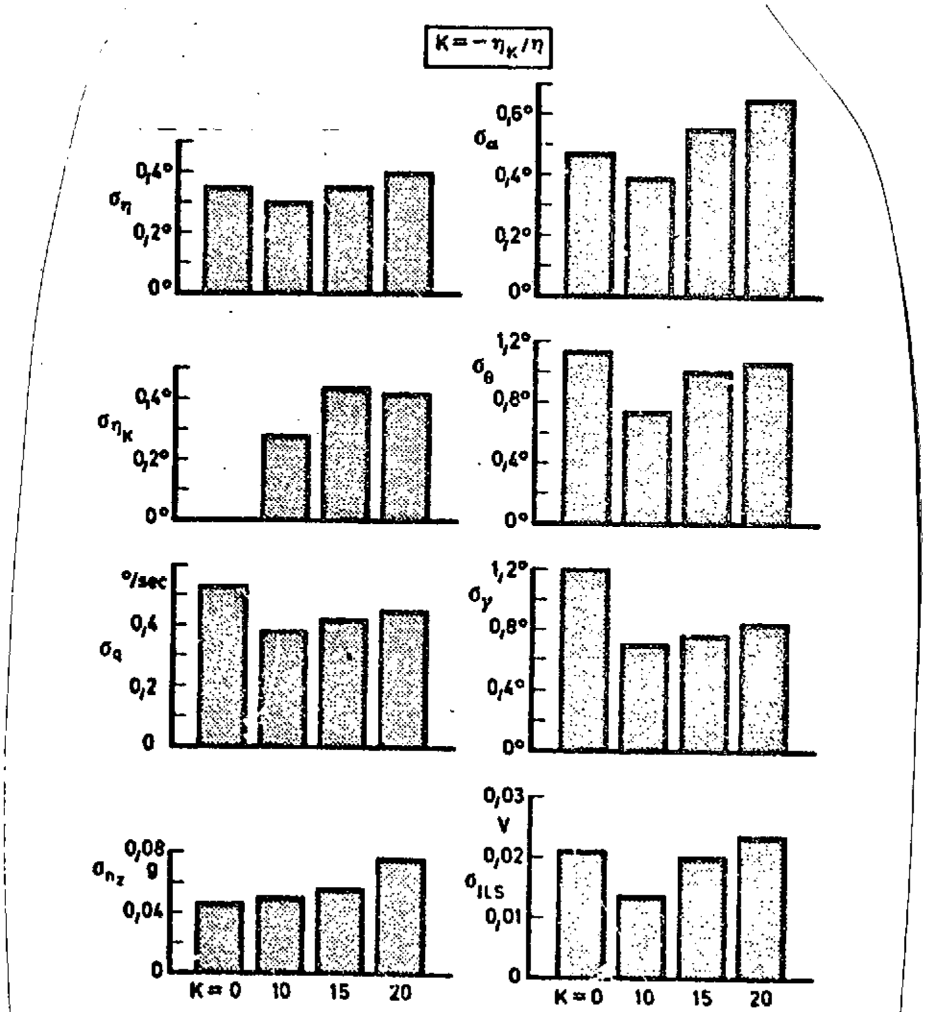


Fig. 14. Comparison of aircraft responses to abrupt-change elevator input with and without DLC (flight test).



(basic) (basic)

Fig. 15. Standard deviation, ILS approaches with and without DLC (flight test).

Key: η_K = Flap angle

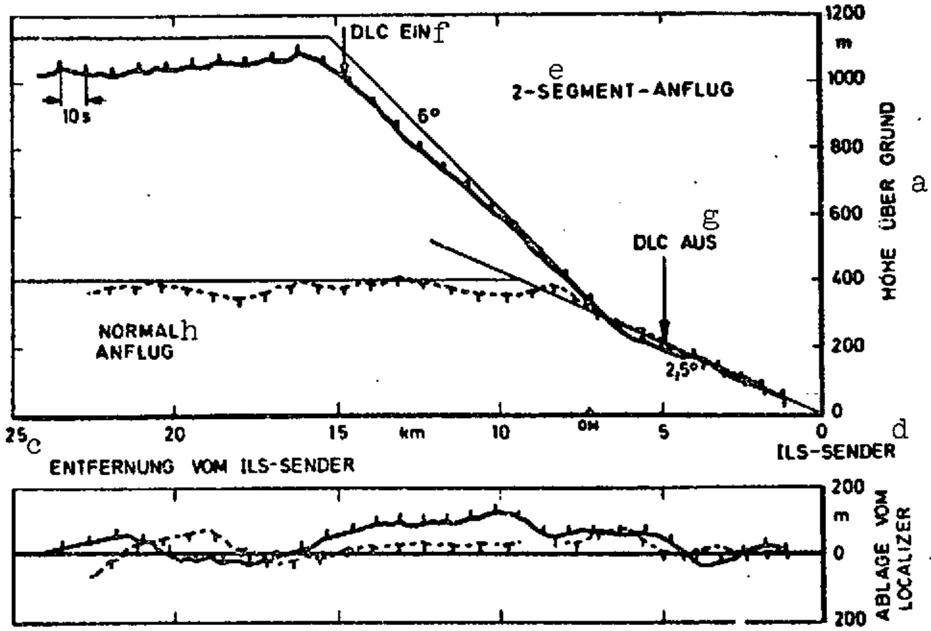


Fig. 16. Standard and steep approaches (flight test).

Key: a. Altitude above ground
b. Displacement from localizer
c. Distance from ILS transmitter
d. ILS transmitter
e. Two-segment approach
f. DLC on
g. DLC off
h. Standard approach

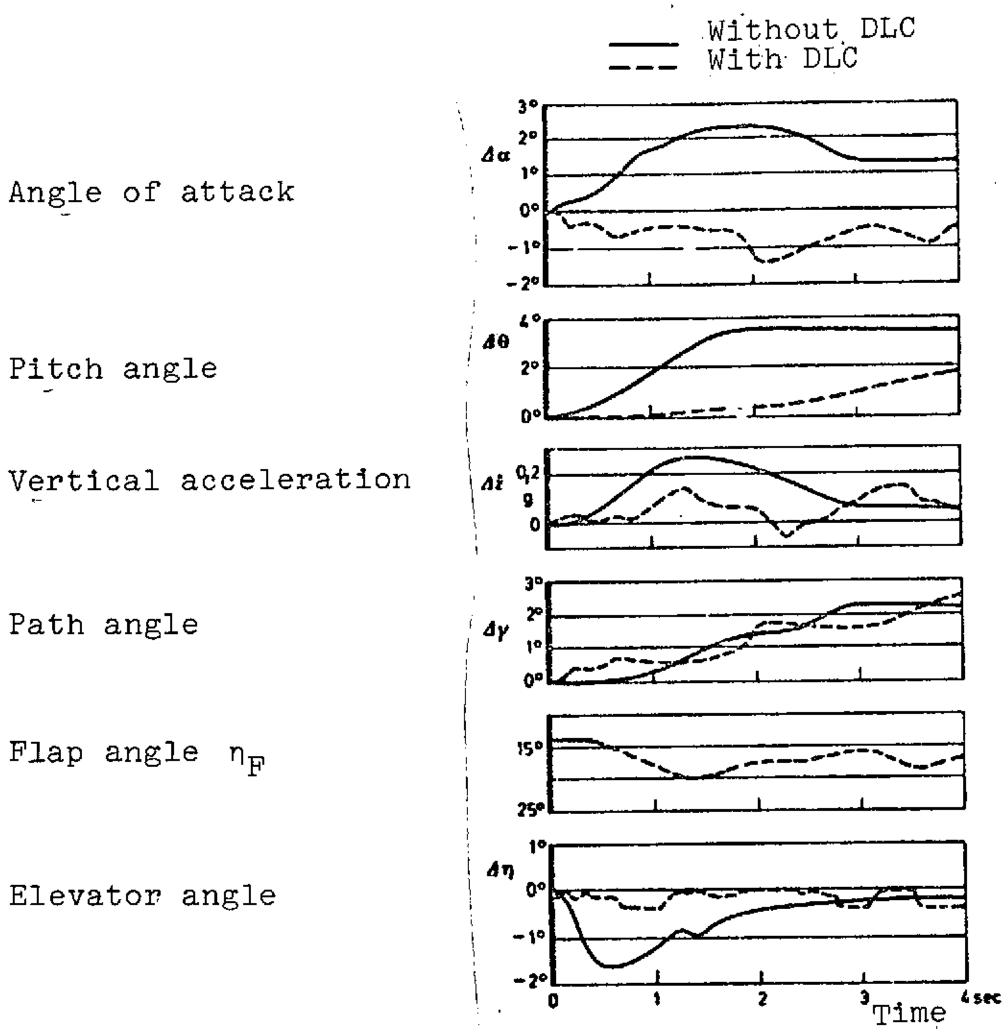


Fig. 17. Approach maneuver from 6° to 2.5° approach path with and without DLC (flight test).

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